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Predictability of Pilot Performance from Simulated to Real Flight in the UH-60 (Black Hawk) Helicopter

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14. ABSTRACT

Despite continued reliance on simulators during training, research, and pilot certification, the predictive relationship of data obtained from simulators and its relevance to the operational reality of flight remains inconclusive. If a pilot shows great proficiency in an aircraft simulator, perhaps the pilot will also exhibit similar levels of proficiency in the actual aircraft. The research presented in this report continues an almost thirty year attempt to establish pilot performance in an aircraft simulator as a valid predictor of anticipated performance in the corresponding aircraft. While a larger sample size may have strengthened the results of this study, it can be concluded that a significant lack of predictability in pilot performance exists from simulated to real flight in the UH-60 helicopter. These results follow and reinforce previous studies conducted in numerous airframes over the last 30 years.

15. SUBJECT TERMS

Black Hawk, pilot performance, flight performance, NUH-60 flight simulator, JUH-60A helicopter

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Background

The accurate measurement of a pilot's performance has been an effort of the aeromedical research community for many years (Rehmann, 1982). Despite continued reliance on simulators during training, research, and pilot certification, the predictive relationship of data obtained from simulators and its relevance to the operational reality of flight remains inconclusive. Why, if a pilot shows great proficiency in an aircraft simulator, can it not be shown that the pilot will exhibit similar levels of proficiency in the actual aircraft? The research presented in this report continues an almost thirty year attempt to establish pilot performance in an aircraft simulator as a valid predictor of anticipated performance in the corresponding aircraft.

The most used method of assuring pilot competence in U.S. Army rotary-wing aviation is the standardized "check ride" conducted by a school trained and currently qualified instructor pilot (IP). This measure of rating performance has the advantage of face validity and can act as a baseline for research purposes; however, it suffers from the individual scorer's variability and experience level, presenting quantification problems during complex and/or ambiguous maneuvers (Anastasi, 1976).

The use of simulators has contributed much towards the understanding of aviation-related problems and the effects of stressors or interventions and pilot performance (Caldwell and Roberts, 2000). While these types of studies have been conducted for more than thirty years (Asknes, 1954), quantitative comparisons between simulator and aircraft performance originally began in 1975, using data obtained from an existing experiment (Billings, Gerke, and Wick, 1975). Many studies have examined physiological strain induced by environmental stressors (Brown et al., 1969), or changes in performance in relation to pharmaceutical interventions (Caldwell, Roberts, and Jones, 1999), and some included measurements of specific maneuvers in each platform (Hasbrook and Rasmussen, 1971). While a single study in fixed-wing aircraft did produce comparable performance measures (Magnusson, 2002), all other comparison studies have shown that there were significant, statistically demonstrable differences in pilot performance between simulated and actual aircraft platforms. However, with the emergence of real-time data collection in the operational aviation environment, researchers are now better able to match relevant data points between platforms during each flight session from selected time points within an individual maneuver, thus permitting a more rigorous examination of performance.

As noted above, flight performance can be measured using subjective evaluation of the pilot during a standardized check ride with an IP and/or by detailed objective analysis of maneuver performance using fully instrumented research flight platforms. The U.S. Army Aeromedical Research Laboratory (USAARL) maintains two systems for objective, real-time measurement of pilot performance, namely the JUH-60A research Black Hawk helicopter and the NUH-60 Black Hawk full motion simulator. These platforms and IP subjective evaluations, present the laboratory with a unique opportunity to quantify flight performance. USAARL has compiled a Pilot Performance Database of over 37 in-flight or flight simulator studies where comprehensive pilot and aircraft performance data were collected, analyzed, and archived. This automated database now contains more than 3 gigabytes of performance data.

During a prior USAARL study of refractive surgery on pilot performance, approximately 68 percent of the research dollars for completion of the protocol were allocated for the use of the Laboratory's JUH-60A research Black Hawk. Per hour cost to fly the Black Hawk was $2367.00 as opposed to $160.00 for the same amount of time spent in the NUH-60 simulator. Examining the line-item cost of flying the Black Hawk helicopter in the research environment reveals expenses of which the researcher may not be aware. While fuel and maintenance are obvious expenditures, actual hours preparing for flight also incur costs. A rough estimate has shown that for every hour (hr) of actual flight, at least 2 hr of preparation and post-flight inspection are required. Also, in USAARL's case, most missions were not flown by active Army aviators but by Department of the Army civilians (DACs) whose salary, currently at over $40.00/hr, must be included. Weather and safety concerns when conducting actual flight increase costs as the subject pilot and research IP await weather conditions within required aviation minimums for protocol flight, in addition to the personnel costs incurred by non-rated technical crew and maintenance support personnel. These costs provide a powerful inducement to use simulators wherever possible, provided that such data will transfer appropriately.

Data obtained for this report came from a request received in July 2001 by the Army Surgeon General. He requested an evaluation by the U.S. Army Aeromedical Activity (USAAMA) to determine whether refractive eye surgery should be favorably considered for Army aviators. This request came out of previous inquiries by the Secretary of Defense as to why the policies for refractive eye surgery for aviators were different across the military services, and from the Secretary of the Army as to why the Army would not consider the same policy as the Federal Aviation Administration (FAA), which allows refractive surgery for civil aviators (Department of Transportation/Federal Aviation Administration, 2005). The primary emphasis of the original study was to systematically determine if there is a measurable change in flight performance due to refractive surgery alone. Subjects who consented for the study were UH-60 pilots, under temporary duty (TDY) orders, and who completed pre- and post-operative visual performance and detailed flight performance testing at USAARL. The study evaluated standard, FDA-approved photorefractive keratectomy (PRK) and laser in-situ keratomileusis (LASIK) procedures to determine compatibility, safety, and efficacy of these procedures for rated Army aviators. Upon completion of the study, recommendations were forwarded to USAAMA for determination of aeromedical policy. Only the pre-operative flight performance data from this study are presented and analyzed in this report.

If it could be shown that performance scoring in the instrumented NUH-60 simulator could be used to predict accurately the scoring of the same subsequent maneuvers in the aircraft itself, future performance studies could possibly obviate the actual flight portion of the protocol and infer rotary-wing flight performance based entirely on the pilot's simulator scoring. This option for data collection and assessment could potentially lower the incurred cost related to the number of actual flight hours currently spent on research protocols. A positive finding might also have implications for pilot training in general.

Methods

The source data is taken from the flight performance outcomes of the 21 subjects who completed pre-operative (i.e., baseline) testing in the USAARL refractive surgery study (OTSG HSRRB Log A-10105.2). Included is a summary of flight performance before and after the surgery (table B-1 of appendix B). Of these 21 subjects, 17 completed all flight performance tests through the 6-month period, the study stopping point. This report uses only the preoperative flight performance data to avoid introducing additional complexity to the analysis caused by the incorporation of variables associated with the refractive surgery procedure.

The experimental flight and vision testing schedule used for these subjects is shown in Table 1.

Table 1.
Preoperative testing schedule (S = day of surgery)

	Day S minus 5 (Vision) USAARL	Day S minus 4 (Simulator) USAARL	Day S minus 3 (Flight) USAARL
Morning	Check-in, Informed consent Med Monitor and Ophthalmologist Survey Vision Tests	Simulator Training Session (1 hr) *verify subject has recovered from cycloplegia	
Afternoon	NVG vision testing Contrast Sensitivity Cycloplegic Exam	Simulator Day Session (1hr)	In-flight Day Session (1hr)
Evening		Simulator Night Session (1hr) Simulator NVG Session (1hr)	In-flight Night Session (1hr) In-flight NVG Session (1 hr) *moon state and luminance will be noted

In this report, all three visual environments, day unaided, night unaided, and night vision goggle (NVG) are included. Two exemplar maneuver types were selected from the flight profile (see tables B-10 and B-11 of appendix B): 70-foot (ft)out of ground effect hovering turns, which were considered "hard" (maneuvers 2 and 15), and straight and level flight which were considered "easy" (maneuvers 4, 8, and 12). For a complete description of each of these maneuvers and the performance parameters scored for reporting see "Flight Maneuvers" below and appendix A.

Experimental apparatus

NUH-60 flight simulator

The USAARL NUH-60 flight simulator is a research tool used to objectively measure aviator performance under controlled environmental conditions. The flight simulator has a 6-degree-of-freedom motion base and a visually complete cockpit including appropriate through windscreen imagery. For the refractive surgery study, the visual displays were set for each luminance condition (day, night-unaided, and night NVG) and simulated a flight in and around Cairns Army Airfield (CAAF), Fort Rucker, Alabama, where the actual aircraft flights occurred. There were no other environmental inputs programmed. Flight data for pilot performance (heading, airspeed, altitude, etc.) were acquired from 128 separate channels at up to 30 Hertz (Hz) and converted to composite data scores utilizing a special in-house produced program named HAWK (for Black Hawk) written in native-mode VAX FORTRAN (Jones and Higdon, 1991).

The HAWK program provides for the collection and analysis of physiological and/or flight performance data from USAARL's NUH-60 Black Hawk simulator. The HAWK program can be executed in two modes, according to the needs of the researcher. The two modes are designated HAWK and PHAWK.

HAWK mode is an installed shared image on the VAX 11-780 computer, which runs multiple tasks to accomplish the various data acquisition tasks. It communicates with a companion process, which is resident in a Perkin-Elmer OFT computer. HAWK mode allows shared monitoring of the real-time data acquisition for any number of users, who can also observe only selected variables of the 128 being sampled. This allows researchers to monitor simulator flights from any computer that is connected to the USAARL network.

PHAWK mode invokes the HAWK program in "private" mode, which is completely independent of any other data acquisition which may be in progress. This program is used to access and process previously stored data according to the users defined needs. Descriptive statistics can be computed as well as user defined performance scores from selected maneuvers and downloaded onto any computer connected to the USAARL network. It can then be analyzed by any commercial statistics and graphics software (SPSS, Excel, etc.).

JUH-60A helicopter

In-flight pilot performance testing was conducted in USAARL's JUH-60A research Black Hawk helicopter. This Sikorsky helicopter is a specially equipped version of the standard U.S. Army UH-60 transport. For data collection an in-flight instrumentation package, the Aeromedical Instrumentation System (AIS), is installed on the helicopter. This system is a locally manufactured computerized pilot performance surveillance package used to collect aircraft maneuver data during flight for later analysis in the laboratory (Mitchell et al., 1988). The system consists of an interconnecting wiring harness, a multichannel signal conditioner, and a computerized data recording system, that draws the raw data directly from the helicopter's instruments. The AIS can provide continuous sampling of up to 128 measurements, such as aircraft performance, position in space, position of pilot controls, G-loading, angular rates, etc.

The data are collected and stored on transportable media for upload to the VAX computer at USAARL. The parameters measured by the AIS during this study are identical to those measured in the simulator and once uploaded to the VAX computer, are processed by the HAWK software.

Subjects

The 21 subjects enrolled in the study, after appropriate screening and informed consent, were experienced and current male Black Hawk pilots with a mean overall rotary-wing flight experience of 1736 hr (range 301 to 5000 hr), mean Black Hawk experience of 812 hr (range 100 to 3000 hr), and mean age of 38 years (yr) (range 28 to 49 yr). All aviators were considered current, by Army regulations, in the UH-60 Black Hawk. An aviator is considered "current" if less than 60 days have elapsed between day flights and less than 45 days have elapsed between NVG flights (AR 95-1). Because of the nature of the underlying experiment all pilots had some refractive error. The mean preoperative optical refractive error for the group was –1.65 diopters spherical equivalent (range +0.75 to –6.00 diopters). All were required by their flight surgeon to wear prescription eyewear in order to fly as noted on their DA Form 4186, Medical Recommendation for Flying Duty. A complete schematic of events for the underlying refractive surgery study from which the data was obtained is shown in figure 1.

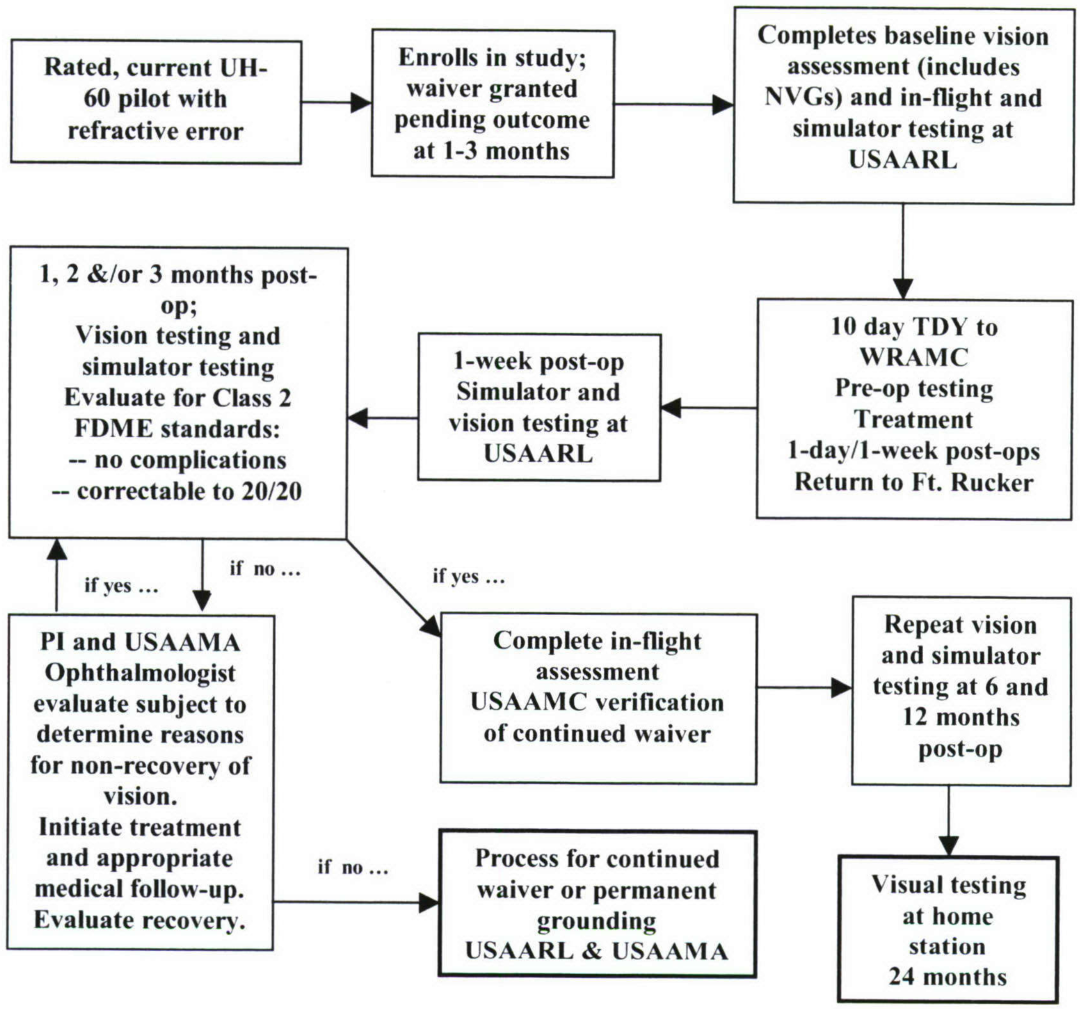

Figure 1. Sequence of events and testing.

Visual environments

Simulator and in-flight testing protocols were used to assess flight performance under all luminance conditions that a pilot might expect to encounter during routine flying missions. These conditions included day, night unaided, and night vision goggle flight. Light and environmental conditions experienced during the flight portion of the study varied from cloudless, bright sunshine days to completely overcast nights with rain. The standard flight profile (see figure 2) was flown for all conditions, except when the flight was cancelled for crew safety reasons. Measurements of luminance during the period of flight were obtained through the local U.S. Air Force meteorological service and, while recorded for most flights, varied among flights to such a degree as to be unusable for analysis. The NVGs used for night-aided flight were standard U.S. Army aviation issue. For simulator flight the ANVIS 6, Type 3 was used and for the JUH-60 flight, the ANVIS 6, Type 2 or 3 was used.

Each subject first completed a 1-hr daylight training flight in the simulator, then 3 hr of simulator testing (1 hr in each luminance condition). This was followed, normally the next day,

by 3 hr of actual in-flight testing. All simulator flights, including the night and NVG conditions, occurred during what would be considered normal duty hours (0730-1630). In all cases, the daylight condition was run first, then the night unaided condition, and finally the NVG condition. No counterbalancing of order across subjects was instituted.

Flight maneuvers

The flight profile and task listings for each time period are provided in appendix A and apply to both simulator and in-flight sessions. Figure 2 shows the general layout of the flight protocol. Flight performance assessments for both the simulator and aircraft were completed for each examination time point. Specific software collection routines were designed to analyze specific maneuvers and were configured to collect only the parameters that were unique for that maneuver and flight profile.

Further analysis was accomplished using the DEC VAX 11-780 computer, in-house analysis programs and commercial statistics/graphics packages to extract descriptive statistics and scores for comparative purposes.

The following flight maneuvers were included in the original refractive surgery flight profile:

a. In ground effect right hovering turn (over airfield and over confined area)
b. Out of ground effect right hovering turn (over airfield and over confined area)
c. Take-off (three times from the airfield)
d. Straight and level flight (three times within the airfield pattern)
e. Right, descending, decelerating turn (twice within the pattern)
f. Landing (one to the ground, one roll-on and one to a confined area)
g. Instrument landing system landing (one to the airfield)

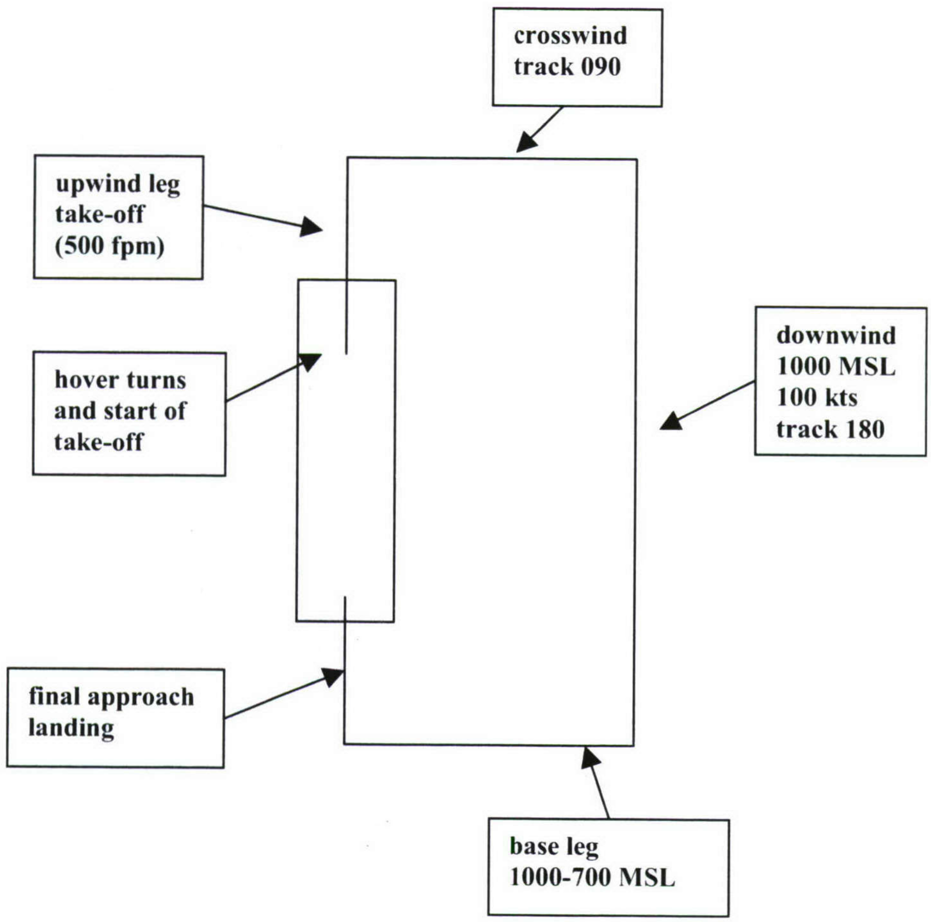

Figure 2. Flight profile diagram

The following paragraphs detail the specific flight performance tasks in the original protocol that were used in this report and list which aspects of aircraft control each task represented.

Out of ground effect (OGE) right hovering turn (tasks 2 and 15) required the subject pilot to coordinate pedal input and cyclic control to pivot the aircraft through 360 degrees around a given point above the ground at a rate of 3 degrees per second. Visually, the pilot must constantly check inside and outside the aircraft to maintain power (by checking the torque), check time, maintain height and position above the ground (read the radar altimeter and the horizontal situation indicator [HSI]) and monitor rate of movement over the ground. There are two hover turn maneuvers, one over the airfield runoff pad and one over a confined, unimproved landing zone. The unimproved landing zone presents decreased contrast for visualization of ground features and can produce illusions caused by grass movement, which make the OGE hovering turn at 70 ft task more difficult. For this analysis, 70-ft hovering turns were analyzed because they were graded as the most difficult tasks of the entire profile. The standard for this task was to complete the turn in the stated time while maintaining height and position $\pm$ 10 ft. These maneuvers require excellent depth perception since detecting movement over the ground is critical to adequately completing these tasks. During the night unaided and NVG flights, additional scanning was required to avoid disorientation due to limited contrast.

When performing the Straight and Level Flight maneuvers (tasks 4, 8, and 12), the pilot, after making two 90-degree turns to the downwind leg of the traffic pattern, was required to hold the aircraft to straight and level flight at 1000 ft MSL and 100 knots. The pilot must monitor airspeed, altitude, heading and trim for 2 minutes while checking outside the aircraft for ground track and airspace surveillance. This was graded as the easiest maneuver of the profile.

For each maneuver type, the maneuver analysis evaluated airspeed, heading, roll, and altitude and calculated deviances from a theoretically perfect maneuver to determine an objective score for that maneuver.

Subjective scores were completed by the IP and were used to augment the data obtained during the flight profiles for both the simulator and in-flight protocols. These flight assessments were based on performance during the flight maneuver profiles as listed in appendix A. All subjective evaluations of the subject pilot were performed either at the time of the maneuver, or in a post-flight debriefing. The IP entered a score from 1 (inadequate) to 5 (exceeds) for each maneuver during the flight with a score of 3 being defined as "to standard." This evaluation was performed for each flight and identified any significant deviations from proper flight procedure in accordance with TC 1-212 Aircrew Training Manual, Utility Helicopter, UH-60/EH-60.

Results

Initial data analysis

A complete within subject design was used in order to make comparisons across actual and simulated missions. In addition to the simulator and aircraft data, an objective of this study was to see how the IP subjective scoring related to the objective data. Each pilot flew missions under three luminance conditions, that is, day unaided, night unaided, and night aided (NVG). Initial analysis was accomplished by averaging the individual scores across all maneuvers for a flight to produce one overall performance score for each flight (i.e. each subject pilot), and for each luminance condition separately. The results for average (A), standard deviation (S), and Pearson product moment correlation (R) for the daylight visual conditions are shown table B-2 of appendix B. The averages for all maneuvers and averages broken out by types of maneuver and luminance condition are shown in tables B-2 through B-8 of appendix B. Comparisons of the correlations between measurement techniques using STD/AVG differences against the mean for simulator versus aircraft, utilizing Bland and Altman plots are seen in figures 3 through 5 (Bland and Altman, 1999).

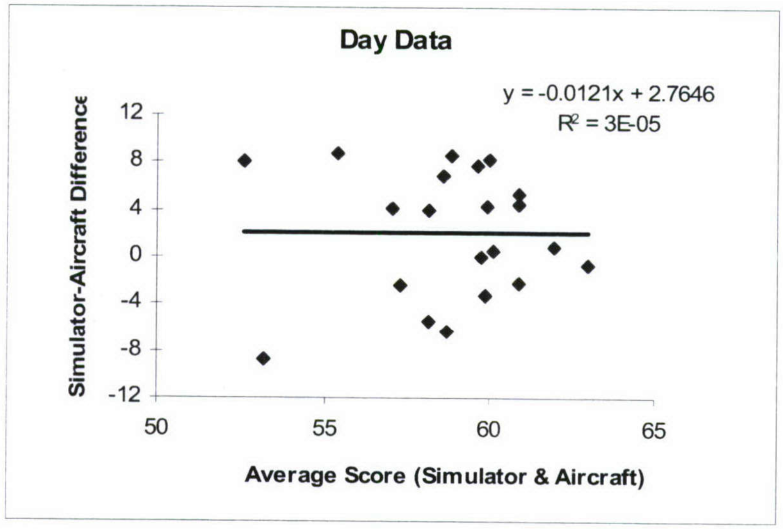

Figure 3. Score difference plotted against average score of simulator and aircraft for the day light data, with a fitted linear regression. Each plotted point is derived from one pilot's scores.

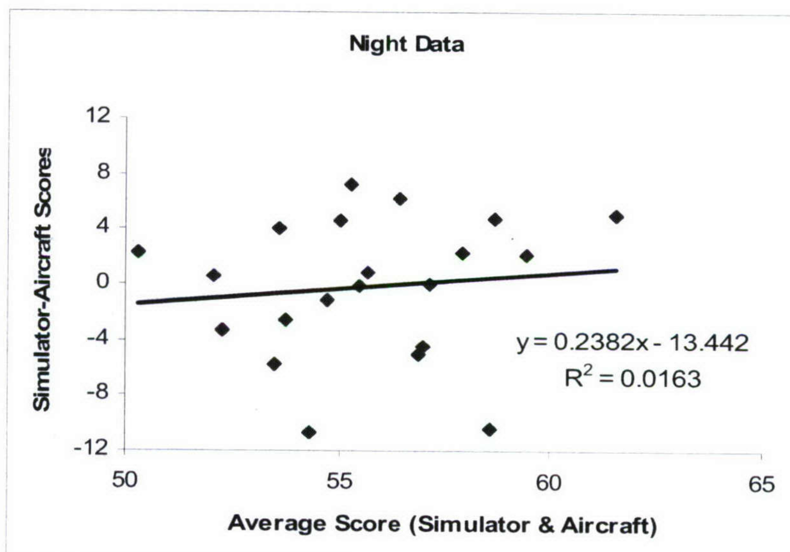

Figure 4. Score difference plotted against average score of simulator and aircraft for the night data, with a fitted linear regression. Each plotted point is derived from one pilot's scores.

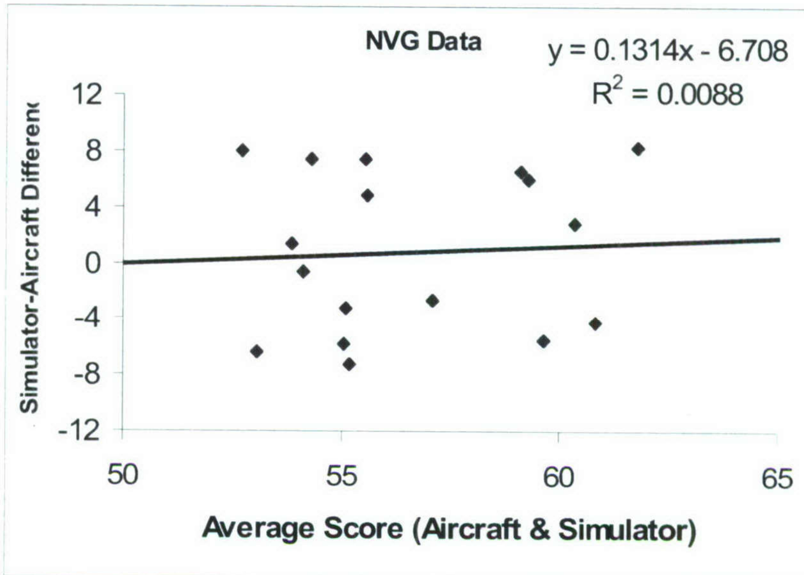

Figure 5. Score difference plotted against average score of simulator and aircraft for the NVG data, with a fitted linear regression. Each plotted point is derived from one pilot's scores.

In each of these Bland and Altman plots, the scatter diagram displays the differences between the simulator and aircraft data vs. the means of the aircraft and simulator scores from the averaged performance on all 16 maneuvers in each platform. Based on the appearance of these plots, there appears to be no correlation between the combined maneuver results from the two platforms.

Since this preliminary analysis combined disparate maneuvers, the negative results might be artefactual. For subsequent analyses, it was decided to focus on only the two previously mentioned sets of maneuvers: straight and level (considered relatively "easy" maneuvers) and hover turns (considered the most "difficult" maneuvers of the entire series). If either of these two data sets shows a significant correlation, then further analysis could be justified.

Detailed data analysis

The simulator and aircraft data reported here were collected in the same manner and provided a dependable way to measure pilot performance. The sample size of 21 subjects tested was only sufficient to report on trends as a group and is less than sufficient for comparison between the aircraft and simulator. Since flight performance is the most important outcome of this report, flight performance data should determine the appropriate sample size. Using the flight outcomes from the study so far as a metric, the power for the combined group (21 subjects) is 66 percent. The goal of the underlying study was to achieve 80 percent power at $\alpha = 0.05$. To achieve this level of power with the variability metric of the flight performance data acquired to date would require 29 subjects as a minimum group. Experience levels of the subjects should not have played a factor in performance due to the within subject design of the experiment.

As noted above, the data set is a nested series of repeated preoperative measures on 21 pilots, limited to the two maneuver types described above. The data set to be analyzed consisted of 126 scores for the aircraft and 125 scores (1 missing datum) for the simulator. The data distribution was examined for normality by fitting the calculated data histograms with Gaussians (see the four panels of figure. 6); the resulting distributions were not significantly different from normal (Chi-square tests, all $p > 0.20$). Accordingly, parametric statistics were used for the remainder of this analysis.

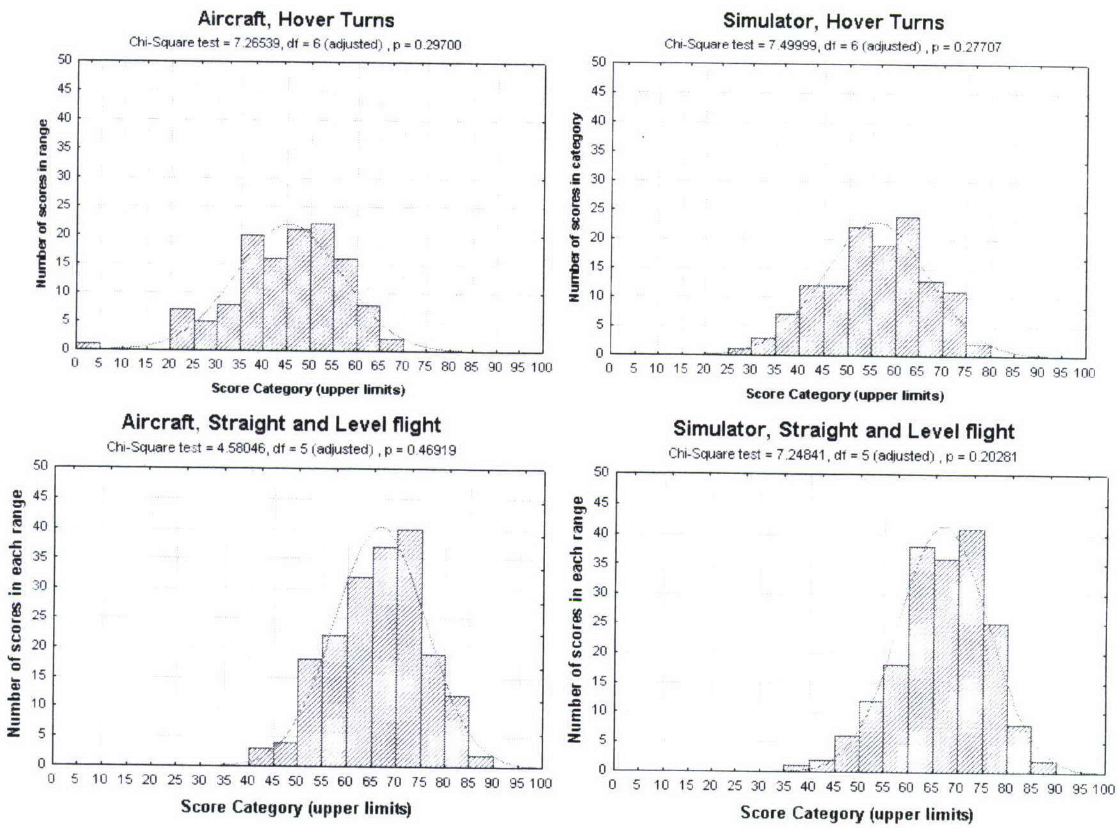

Figure 6. Data histogram distributions.

The left column of plots above is from the aircraft data, the right from the simulator data; the top row is for the difficult hover turn maneuvers and the bottom for relatively easy straight and level flight.

Pearson correlations were calculated between the aircraft and simulator data, and are plotted for the hover turn maneuvers in figure 7, and for the straight and level flight in figure 8.

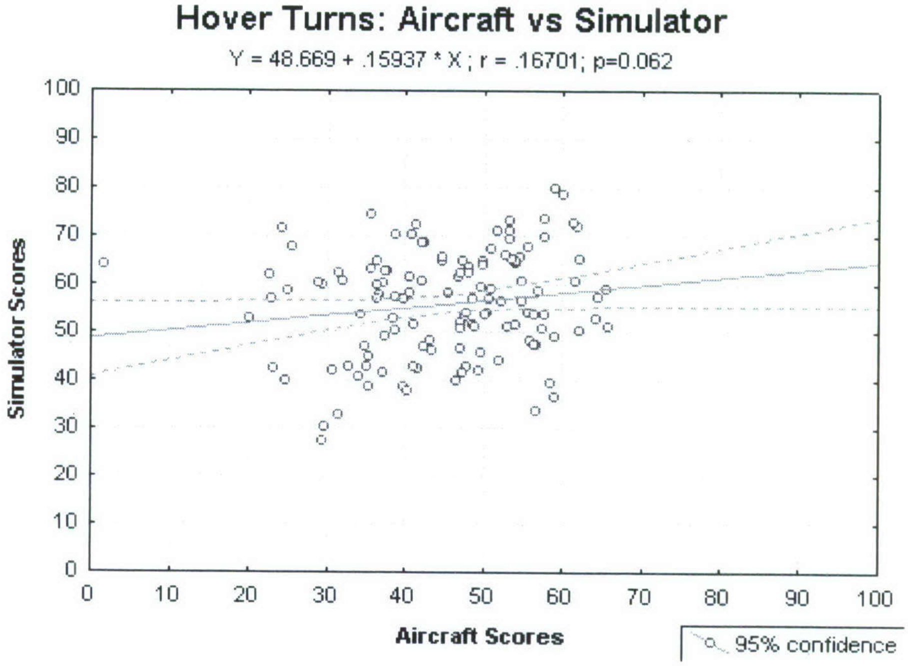

Figure 7. Aircraft vs. Simulator scatter plot, hover turn maneuvers.

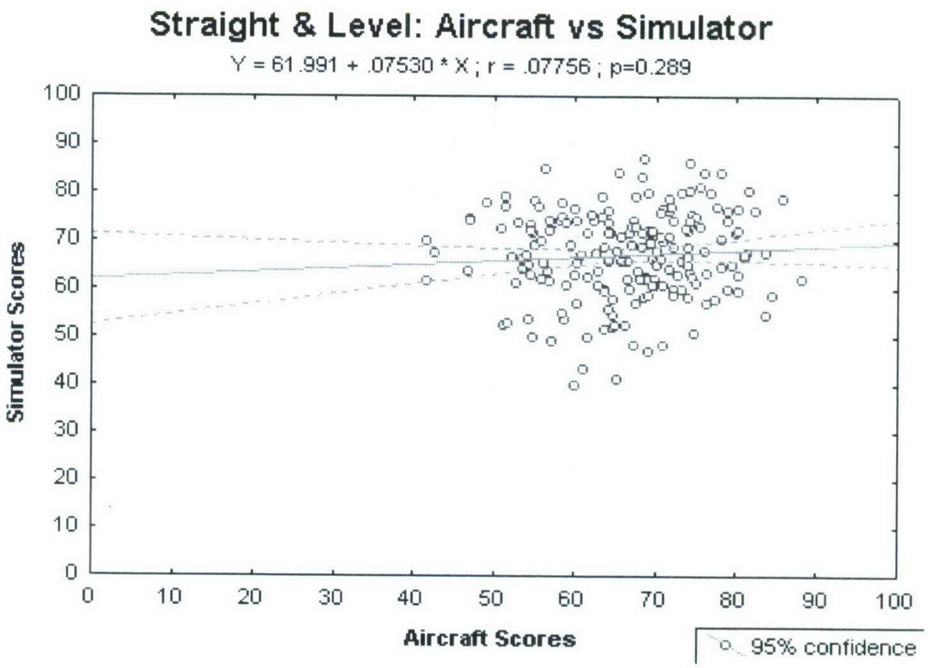

Figure 8. Aircraft vs. Simulator scatter plot, straight and level maneuvers.

As can be seen, the fitted lines relating the simulator data and the aircraft data have very low slopes and the data show a large scatter. Neither correlation was significant, although the difficult maneuver data approached significance ($p = 0.062$). Since the slopes are almost flat, the variance in the data explained by the correlation is negligible (2.5 percent in the hover turn case).

This raises the question of which factors might be responsible for reducing the predictive ability of the simulator data for the aircraft data.

Analyzing the data in a general linear model with repeated measures (condition, maneuver, and platform) for the hover turn data only showed significant main effects due to condition (day, night, or NVG) and platform (aircraft or simulator). The two maneuvers comprising the hover turn data (2 and 15) were not significantly different, as expected (table 2).

Table 2.
General linear model with repeated measures for the hover turn data.

	Test	Value	*F*	Effect	Error	*p*
Platform (Aircraft, Simulator)	Wilks	0.426729	26.86817	1	20	**0.000045**
Maneuver (2, 12)	Wilks	0.985056	0.30341	1	20	0.587854
Condition (Day, Night, NVG)	Wilks	0.347712	17.82142	2	19	**0.000044**
Platform*Maneuver	Wilks	0.767504	6.05851	1	20	**0.023053**
Platform*Condition	Wilks	0.997797	0.02097	2	19	0.979271
Maneuver*Condition	Wilks	0.890426	1.16905	2	19	0.332033
Platform*Maneuver*Condition	Wilks	0.736335	3.40173	2	19	0.054603

The means and 95 percent confidence intervals are graphed below (figure 9):

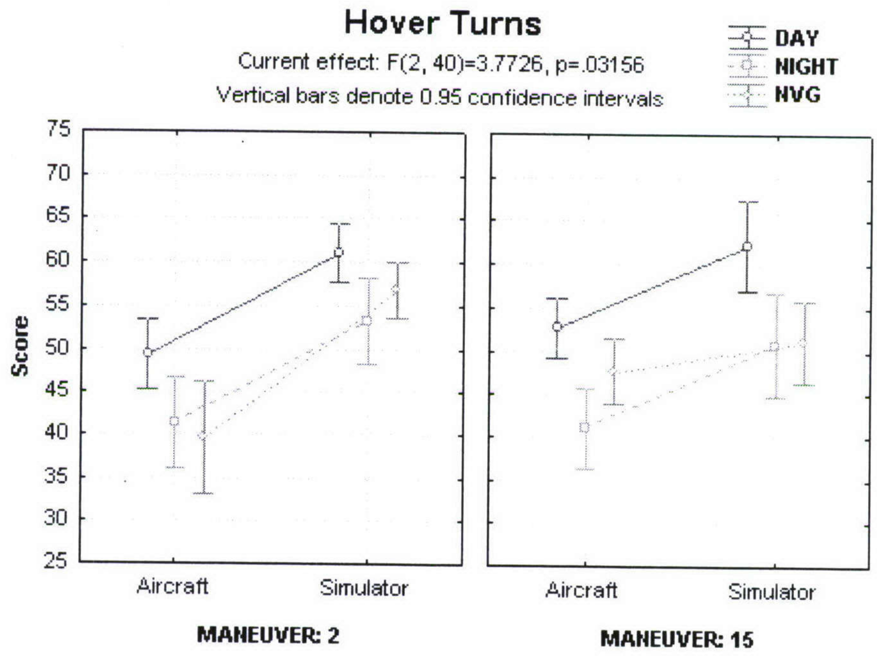

Figure 9. Means and 95 percent confidence levels by maneuver, hovering turns.

As is apparent by inspection, daytime conditions resulted in improved scores compared to nighttime and NVG conditions, and aircraft data lies below simulator data.

For the straight and level flight data, surprisingly only the individual maneuvers (4, 8, and 12) showed a significant main effect (table 3).

Table 3.
General linear model with repeated measures for straight and level maneuvers.

	Test	Value	F	Effect	Error	P
Platform (Aircraft, Simulator)	Wilks	0.997522	0.049688	1	20	0.825867
Maneuver (4, 8, 12)	Wilks	0.687916	4.309816	2	19	**0.028615**
Condition (Day, Night, NVG)	Wilks	0.819374	2.094211	2	19	0.150689
Platform * Maneuver	Wilks	0.984541	0.149167	2	19	0.862424
Platform * Condition	Wilks	0.933163	0.680432	2	19	0.518317
Maneuver * Condition	Wilks	0.924354	0.347805	4	17	0.841901
Platform * Maneuver * Condition	Wilks	0.458839	5.012502	4	17	0.007452

The results are graphed below (the vertical scale is the same as the previous graph to permit visual comparison) (figure 10). By inspection, maneuver 4 was performed with less accuracy than maneuvers 8 and 12, possibly because this maneuver was executed very early in the mission. Of interest in these maneuvers, the data show performance in the aircraft to trend occasionally above that in the simulator specifically maneuver 8 in daytime conditions; however, the variances in the data are too large for speculation.

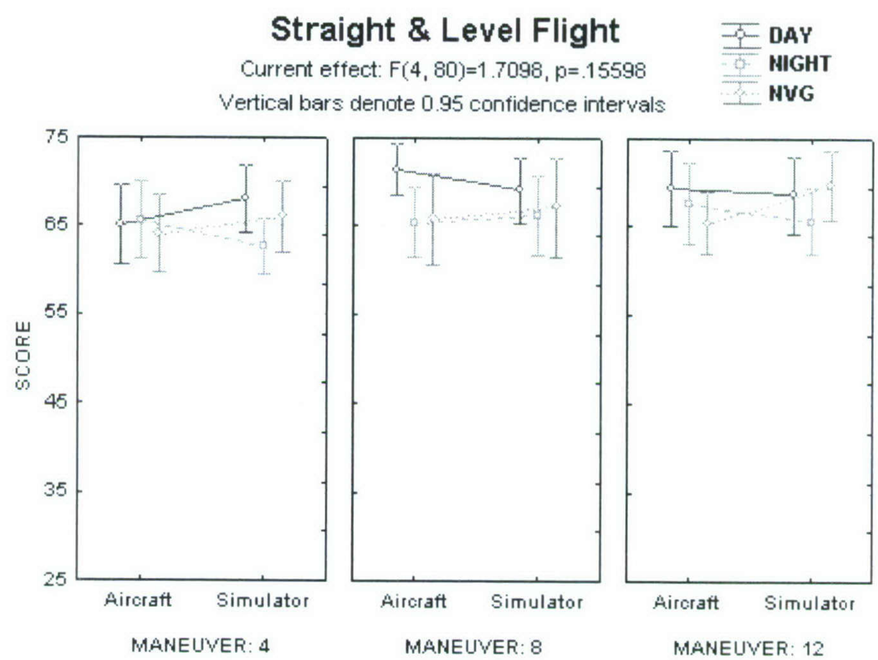

Figure 10. Means and 95 percent confidence levels by maneuver, straight and level flight.

Instructor pilot subjective scores

Instructor pilot (IP) subjective scoring was used to augment the data obtained during the flight profiles for both the simulator and in-flight protocols (see Methods, above). As noted in the Methods, the research IP observing the flight recorded a score using a Likert Scale from 1 (inadequate) to 5 (exceeds standard) for each maneuver performed, either immediately after the maneuver or during the post-flight debriefing. Comments concerning significant weather or other nonstandard flight events were also recorded. These results are listed in table B-11 of appendix B.

The Likert scores were used to construct cumulative (Pareto) diagrams in order to provide guidance on subsequent analyses (figure 12). Since Likert scores are not normally distributed, non-parametric statistical methods were selected.

All the dotted (simulator) curves fall to the left of the solid (aircraft) curves in both the difficult (hover turn) and the simple (straight and level) maneuvers, and are more pronounced in the hover turn case. These data show that the Likert scores are more biased towards lower figures (worse performance) for the simulator as compared to the actual aircraft. The plots also indicate the NVGs appear to reduce slightly the difference between the simulator and the actual aircraft in hover turns but exaggerate the difference in straight and level flight. Table 4 shows the Spearman Rank Order correlations between the simulator and aircraft Likert scores for each subject.

Table 4.

Spearman rank order correlations by maneuver and condition, subjective scores.

Aircraft vs. Simulator	Day	Night	NVG
Hover Turn 2	-0.278	0.259	-0.175
Hover Turn 15	0.100	-0.033	0.360
Straight/Level 4	-0.123	0.332	0.136
Straight/Level 8	0.167	**0.470**	0.259
Straight/Level 12	0.126	0.063	0.213

Note: Most correlations are near zero, and only one (**bolded**) is significant at $p \leq 0.05$.

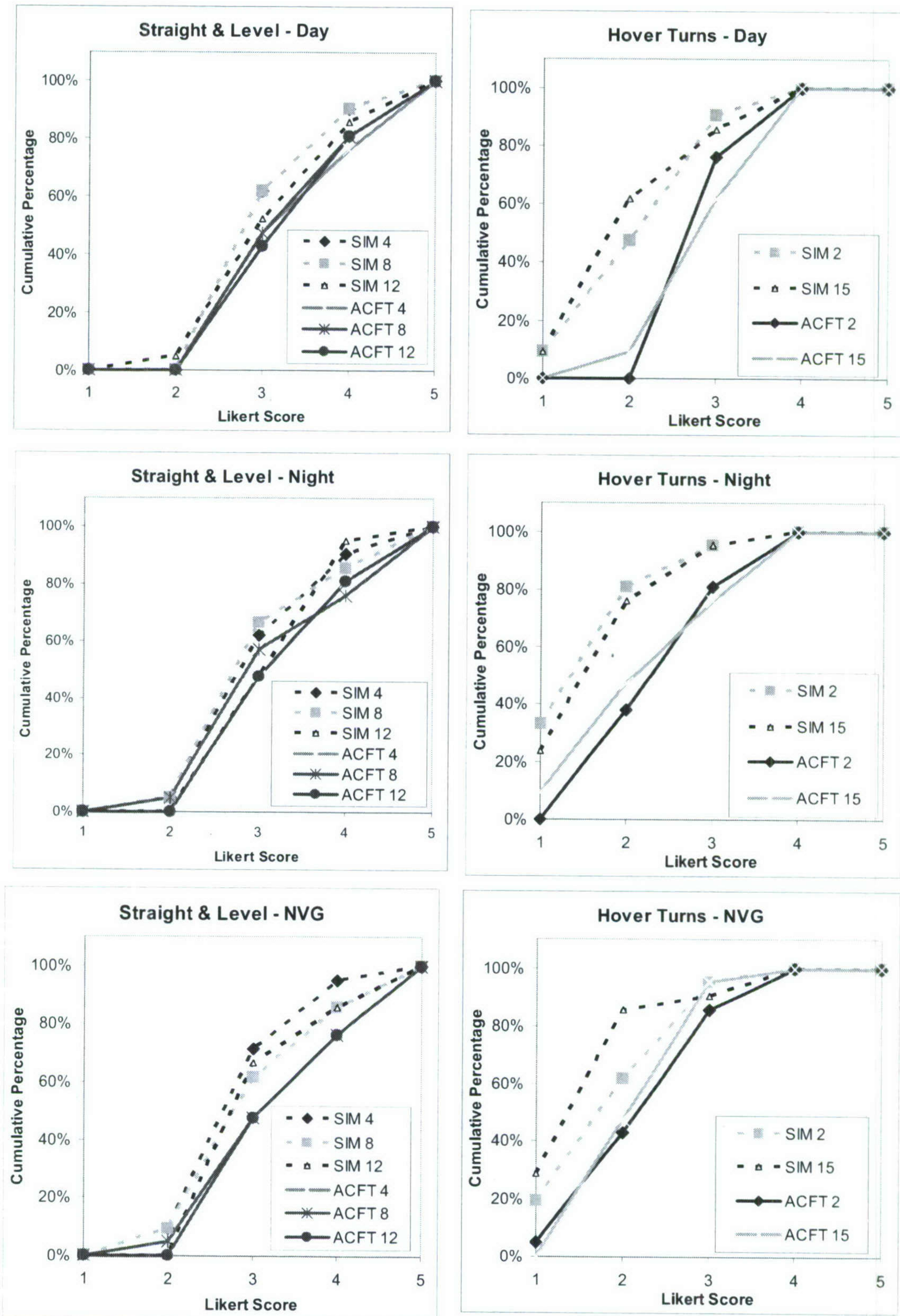

Figure 12. Pareto diagrams of IP Likert scores, for both hover turns and straight and level flight in all three conditions.

Finally, the Likert data were compared with a Mann-Whitney U test by variable "platform" (simulator vs. aircraft), separated by type of maneuver (straight & level and hover turn) and by condition (day, night, NVG). The p values are presented in table 5.

Table 5.
Aircraft and simulator subjective ratings by maneuver type and lighting condition

	Day	Night	NVG
Straight & Level	0.12253	0.22814	**0.02512**
Hover Turns	**0.00003**	**0.00028**	**0.00432**

Note: Mann-Whitney U results ($p < 0.05$ are **bolded**).

As might be expected from the Pareto diagrams above, the hover turns show significant differences between the platforms in all three lighting conditions. Further, the apparent worsening of the straight and level flight ratings seen in the Pareto diagrams above for the NVG condition also proved significant.

Discussion

Pilot performance before surgical intervention, the focus of this report, showed no correlation in the initial statistics between performance scores registered in the simulator versus the aircraft. Further, more detailed correlation analyses performed to determine the degree of association between perceived sets of easy and difficult maneuvers in the simulator and aircraft also proved nonsignificant. Objectively, the hover turn was performed better in the simulator but scored subjectively worse by the IP; scores and evaluations of straight and level flight showed no such disjunction, nor any overall differences on average. Nevertheless, for each pilot, performance in the individual maneuver in one platform could not predict performance either individually or as a group, performance in the other platform.

Differences between performance in the simulator versus the aircraft seen during straight and level flight and hovering turns demonstrate that predictions of performance between the separate platforms cannot be made from the available data. The analysis was able to show however where the most significant deviations occurred. The two overriding contributing factors to difference in performance between platforms were the flight environment in which each mission was flown and the unknown influence of psychological factors associated with the dangers inherent in aviation operations present in the aircraft, but not in the simulator (Caldwell and Roberts, 2000).

The primary factor that could explain little or no association between the platforms is weather turbulence and its effect on an aircraft in flight. There was no way to accurately predict or quantify the weather during each subject's data collection period. Using the limited amount of days available, all attempts were made to schedule flights during periods of good weather. In the case of this study, the minimums for safe flight were set at 3 miles (mi) visibility and a 1000-ft ceiling for day flight; and 3 miles visibility and a 1500-ft ceiling at night. It was within these

parameters that the flights occurred. On several occasions during the study, flights were aborted and rescheduled due to deteriorating conditions below safety standards.

In actual flight, the pilot is constantly making minor corrections to account for random flight path deviations. This has the effect of reducing accuracy of in-flight performance when the pilot must correct for unpredictable deviations in the flight path caused by wind gusts or thermal air currents. In the simulator, the experimenter controls all variables in an air conditioned environment. Since it was impossible to predict the weather the pilot would experience during the corresponding aircraft flight, the simulator missions were flown without any additional environmental inputs save illumination levels.

Variations in luminance were dependent upon lunar phases and environmental conditions present when the actual night and NVG flights occurred. No attempt was made to simulate luminance in the simulator other than flights were conducted at night in a blacked out simulator. Additionally, simulator flights were normally flown during daylight hours, simulating the dark environments of actual night and NVG flight. This may have contributed to higher scoring as a factor of alertness by slewing the pilot's circadian rhythm. Examples of this occurred during the flights actually flown at night, even though the pilot was afforded adequate rest periods before the night flight. Additional factors included the wide variability in moon luminance from one testing period to the next based on the lunar phase and prevailing weather conditions the night the aircraft was flown. It was impossible to maintain a constant illumination from one test period to another. Our particular flights ranged from full moon, unlimited visibility nights, through all intermediate conditions to complete overcast and bare minimum for safe flight, defined for this study as 3500-ft ceiling and 3 mi visibility. Also, during this study a number of IPs were used based on crew rest cycles and mission conflicts.

Of lesser concern was the fact that simulator flights in all conditions were conducted exclusively during the duty day whereas low illumination aircraft flights were necessarily flown at night. This situation (daylight flying of nighttime conditions) might be expected to improve simulator performance versus aircraft performance, as noted in the objective scores, but not the subjective evaluations. Lastly, in the simulator, there were no delays caused by heavy aircraft traffic in the area or maintenance delays from equipment malfunctions or failures.

Despite all attempts to eliminate variables between the two platforms, one performance factor ultimately must be addressed. A major reason for a higher pilot performance score in the aircraft is the fear of crashing. The pilot would necessarily be more aroused and vigilant due to the inherent dangers in the actual rotary wing environment. In almost all cases, a crash in the simulator is a mere annoyance as opposed to crashing the actual helicopter and the consequences thereof.

Differences in subjective scoring of pilot performance can be attributed to the fact that five different IPs were used during the course of the study and each IP had a slightly different set of personal standards as to what constituted an acceptable, or "within standards" maneuver. Weather and the amount of ambient nighttime illumination also could have affected the IP's subjective scoring. In conversation with the most experienced of the IPs, it was relayed that during periods of difficult weather the scorers tried to compensate the subject's score to take this

into account. Finally, in a real environment, the IP is likewise subject to the turbulence, etc. of that environment, and thus may be expected to grade more leniently than in a more optimal simulator environment. This factor may be the explanation for the disjunction between the objective and the subjective results for the hover turn maneuver.

Finally, it must not be overlooked that there are advantages to each method of assessing pilot performance (i.e., simulator vs. aircraft). The simulator is safer, of course, but the aircraft is more "realistic." In practice, the experimental aircraft flight is generally time-limited for logistical reasons (e.g., cost, schedule, subject availability), thus the aircraft flight may be paradoxically less realistic than the simulator flight. While it is true that the possibility of crashing in the real aircraft induces stress, the simulator may be more sensitive to operational effects of interest purely because of the reduced alertness factor. Although missions are often 6 to 8 hr long in Iraq, experiments of such length are generally unfeasible in the actual research aircraft. In this example of the refractive surgery study, there could be interactions between fatigue and visual performance in the "real world" that might not surface in a brief 1-hr simulated flight profile. Conversely, some studies must be conducted in the real aircraft to produce valuable results. For example, studies requiring realistic stimulation of the vestibular system, accurate vibration exposures, or true depth of field/stereopsis, might only be meaningful in the real aircraft environment.

Conclusions

The use of operational aircraft to conduct research studies is filled with dangers. The very nature of rotary wing flight lends itself to disaster when not approached with the utmost respect and caution. Even with the use of highly trained maintenance crews and skilled research pilots there is always the element of the unknown. Thus, it would be a benefit to the rotary-wing aviation research efforts if pilot performance in an aircraft simulator could be directly correlated to that same pilot's performance in the actual aircraft, resulting in significant cost savings.

All data reported in this report were collected and processed using essentially the same methods and equipment. This method of data collection has been proven to be appropriate to assess pilot performance in a dependable fashion. There are a number of possible reasons that performance in the simulator may not be predictive of performance in the actual aircraft, even though the computerized measurement system used in this study was similar between both platforms. Further, the shifting expectations of human raters across different environments must also be taken into account.

While a larger sample size could have strengthened the results of this study, it can be concluded that a significant lack of predictability in pilot performance exists from simulated to real flight in the UH-60 helicopter. These results follow and reinforce previous studies conducted in numerous airframes over the last 30 years. In any research program or study, whether involving pilot stressors or not, the simulator is a powerful and valuable tool. Although assessing pilot performance in the simulator provides valuable information and maximizes cost savings, performance in the simulator may not be the best predictor of performance in the aircraft. Therefore, it is recommended that human research studies implementing real-world

operational scenarios, first be thoroughly assessed in the flight simulator prior to application in the actual aircraft, whenever practicable.

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Appendix A.

Flight performance assessments.

After train-up in the Black Hawk simulator, pilots flew a 1-hr flight profile in the NUH-60 Black Hawk simulator and the UH-60 Black Hawk aircraft under day, night unaided and NVG conditions. The following flight maneuvers were included in the profile:

Administrative Flight to Airfield (not collected). The safety pilot takes the controls during this portion of the flight, and the subject is tasked to determine and set proper frequencies and set instruments for the initial part of the flight. This skill requires adequate visualization of the frequency dial to set the numbers correctly.

Right Hovering Turn (tasks 1 and 2). This requires the subject pilot to coordinate pedal input and cyclic control to pivot the aircraft through 360 degrees around a given point above the ground. Visually, the pilot must constantly check inside and outside the aircraft to maintain power (by checking the torque), check time, maintain height and position above the ground (visualize the radar altimeter and the horizontal situation indicator (HSI)), and monitor rate of movement over the ground. There are two hover turn conditions, the in-ground effect (IGE) at 10 feet and the out-of-ground effect (OGE) at 70 ft. Standards for these tasks are to complete the turns in the stated time while maintaining height and position ± 3 feet for the IGE hover turn and ± 10 ft for the OGE hover turn. These maneuvers require excellent depth perception since perception of movement over the ground is critical to adequately completing these tasks. During the night unaided and NVG flights, additional scanning is required to avoid disorientation due to limited contrast.

Visual Meteorological Conditions (VMC) Take-off (task 3). Take-off from the ground requires balancing input to the cyclic, collective, and pedals of the aircraft to maintain heading and the proper amount of acceleration. During the take-off sequence, the pilot must maintain 10 percent above hover power for acceleration to the required airspeed of 80 knots (± 10 knots), requiring vigilance of torque, heading, altimeter, and airspeed indicators; maintain the desired rate of climb of 500 feet per minute (± 100 fpm) by monitoring the instantaneous vertical speed indicator (IVSI); and sustain track across the ground while minimizing drift. Up to 50 ft above ground level (AGL), the pilot maintains aircraft heading (± 10 degrees), and above 50 ft AGL, the aircraft must be placed in trim while maintaining track to minimize drift. Visually, the pilot must alternate between checking inside to maintain speed, rate of climb, power (monitor torque), and heading and checking outside to maintain ground track and airspace surveillance. At 400 AGL, the pilot initiates a 90-degree turn to start the crosswind leg and continues the climb until the aircraft reaches 1000 ft mean sea level (MSL). For the night unaided and NVG conditions, the lack of visual references may make it difficult to maintain the desired ground track; more attention will have to be paid to surface wind direction and velocity.

Straight and Level (task 4). Prior to this task, the pilot will make another 90-degree turn to the downwind leg. To hold the aircraft to straight and level flight at 1000 ft MSL and 100 knots, the pilot must monitor airspeed, altitude, heading, and trim while checking outside the aircraft for ground track and airspace surveillance.

Decelerating Descent (task 5). To initiate this maneuver, the pilot must lower the collective to establish the proper rate of descent. The pilot has to monitor the IVSI to establish the 500 fpm descent rate, and then starts a 90-degree turn reducing airspeed to 80 knots to enter the base leg at 700 ft MSL. Crosschecks between aircraft flight instruments and the horizon and ground position are important for this maneuver.

Final Approach (task 6). This task starts upon the 90-degree turn into final. The pilot must determine an approach angle that allows safe obstacle clearance while descending to the intended point of landing, in this case the departure or far end of the runway. Depth perception is very important for this task, as the pilot must maintain 80 knots until apparent rate of closure starts to increase, approach angle, minimize drift and stay on track. The pilot maintains ground track alignment with the landing direction by maintaining the aircraft in trim above 50 ft AGL and slips (aligns) the aircraft to maintain the landing direction and straddles the center line of the runway below 50 ft AGL.

Take-off, Straight and Level, and Base Leg tasks are repeated (tasks 7 through 9). The only addition to this sequence is the presentation of an emergency procedure requiring the pilot to visualize a control panel button and to take appropriate action.

Roll-on Landing (task 10). The roll-on landing requires the pilot to maintain a constant approach angle clear of obstacles to the desired point of touch-down, in this case the "departure" end of the runway. The pilot must maintain ground track alignment with the landing direction and perform a smooth, controlled touchdown above effective transnational lift (ETL) but below 60 knots ground speed aligned with the landing direction (± 5 degrees). This task is more visually challenging than the VMC approach, requiring excellent depth perception to maintain rate of closure and runway alignment. At night or under NVG conditions, judging altitude, apparent ground speed, and rate of closure are more difficult due to decreased visual cues.

Take-off and Straight and Level are repeated (tasks 11 and 12). These tasks involve the same requirements as tasks 4 and 5.

Administrative Flight to Confined Area by Safety Pilot (not collected). During this portion of the flight profile, the subject will be required to determine the proper frequency for the area from the provided frequency sheet and will set the FM frequency. This task tests near visual acuity and, under night and NVG conditions, it tests near acuity under low contrast, low luminance conditions.

VMC Approach into Confined Area (task 13). The primary difference between this approach and the standard approach to the runway (task 7) is the lack of contrast introduced by the terrain. The pilot will have to pay particular attention to the radar altimeter and monitor the aircraft heading to prevent drift. At night, the use of the landing light introduces additional visual difficulties, which must be overcome using proper scanning techniques.

Right Hovering Turn above Confined Area (tasks 14 and 15). These tasks are identical to tasks 1 and 2, with the additional factors of decreased contrast for visualization of ground

features and illusions caused by grass movement, which make the tasks more difficult, especially at IGE levels.

Admin Vectors to ILS (not collected). The safety pilot takes the controls during this segment of flight. The subject's tasks will include determining frequencies using the approach plate for Cairns Army Airfield, setting frequencies for both the VOR/ILS (very high frequency omni-directional/instrument landing system) radio, and setting the Automatic Direction Finder (ADF). The subject will select the inbound course for ILS into the HSI and ensure that proper selections have been made on the mode select panel for the VOR/ILS and ADF/VOR.

Instrument Landing System, Runway 6, Cairns AAF (task 16). This task has the highest near visual demand of all the maneuvers due to the requirement to constantly cross-check a number of instruments. Instrument cross-check is observing and interpreting two or more instruments to determine altitude and aircraft performance. In instrument flight, instruments must be properly cross-checked and correctly interpreted to detect any malfunction and to control the aircraft in the desired flight path. Instruments provide: (a) a reference of aircraft attitude; (b) a reference for use of power; and (c) an indication of whether the combination of attitude and power is producing the desired performance. The course deviation bar, the roll command bar, and the pitch command bar in the Vertical Situation Indicator (VSI) must be monitored. Altitude, airspeed, torque, and heading are also monitored. Control and trim techniques used during instrument flight are identical to those used during visual flight. In fact, all the factors relevant to a standard landing are relevant to an ILS approach, except that the approach and landing are controlled via instruments.

Admin Flight to Home Airfield (not collected). The safety pilot regains control of the aircraft for return to home airfield. During this portion of the flight, the subject will be required to respond to an in-flight emergency. This requires reading the emergency procedure sheet and taking corrective action. This is primarily a near acuity task and is more difficult under low light and NVG conditions.

Instructor pilot evaluations (completed by the safety pilot) will be used to augment the data obtained during the flight profiles for both the simulator and in-flight protocols. The flight assessments will be based on performance during the flight profiles. It was not feasible for the safety pilot to note the performance of each maneuver during the flight; therefore, assessment was made after each flight that identifies any significant deviations from proper flight procedure in accordance with TC 1-212 Aircrew Training Manual, Utility Helicopter, UH-60/EH-60. The researcher aviator observing the flight entered a score from 1 to 5 for each maneuver during the flight, 3 being to standard.

Appendix B.

Simulator and flight performance data.

Table B-1.
Simulator and aircraft mean flight performance.

	LASIK		PRK	
	Simulator	Aircraft	Simulator	Aircraft
Pre-op (baseline)	60.81 (2.65)	56.41 (3.99)	59.03 (4.53)	55.13 (3.20)
1 week	58.75 (2.36)	N/A	57.47 (2.86)	N/A
1 month	59.26 (3.61)	58.70 (3.43)	56.50 (5.32)	55.55 (4.38)
6 months	58.58 (3.42)	57.93 (3.42)	57.79 (3.25)	55.66 (4.14)

Note: Results presented as score on a 0 to 100 scale. Pilots were not tested in the aircraft at one week.

Table B-2.
Rated aviator preoperative day comparison including BIN data.

Subject	Simulator	Aircraft	*SD*	*M*	S-A Diff	*r*	
1	62.08	57.74	3.07	59.91	4.34	-0.02649	
2	60.15	56.21	2.79	58.18	3.94		
3	63.51	55.76	5.48	59.64	7.75		
4	56.12	58.48	1.67	57.30	-2.36		
5	59.76	59.74	0.01	59.75	0.02		
6	64.11	55.83	5.85	59.97	8.28		
7	59.14	54.96	2.96	57.05	4.18		
8	60.40	59.84	0.40	60.12	0.56		
9	55.56	61.82	4.43	58.69	-6.26		
10	62.59	63.36	0.54	62.98	-0.77		
11	58.23	61.43	2.26	59.83	-3.20		
12	56.63	48.52	5.73	52.58	8.11		
13	59.82	62.00	1.54	60.91	-2.18		
14	63.16	54.54	6.10	58.85	8.62		
15	63.54	58.25	3.74	60.90	5.29		
16	63.09	58.65	3.14	60.87	4.44		
17	55.40	60.95	3.92	58.18	-5.55		
18	62.07	55.15	4.89	58.61	6.92		
19	62.41	61.57	0.59	61.99	0.84		
20	59.75	50.97	6.21	55.36	8.78		
21	48.87	57.55	6.14	53.21	-8.68		
				Simulator		Aircraft	
	Simulator	Aircraft	Bin	Bin	Frequency	Bin	Frequency
M	59.83	57.78	45	45	0	45	0
SD	3.72	3.74	50	50	1	50	1
Median	60.15	58.25	55	55	0	55	3
Min	48.87	48.52	60	60	9	60	11
Max	64.11	63.36	65	65	11	65	6
Range	15.24	14.84	70	70	0	70	0
				More	0	More	0

Table B-3.
Summary of aircraft flight maneuver data preoperative day.

	ALL *M*	ALL *SD*	HOV *M*	TO *M*	SL *M*	RDT *M*	LND *M*	ILS *M*
1	57.74	13.36	63.71	54.53	62.10	44.16	52.26	73.98
2	56.21	14.80	58.98	59.32	65.97	37.13	55.06	48.17
3	55.76	10.95	57.34	43.33	66.02	50.74	63.08	44.09
4	58.48	13.02	61.55	52.74	65.05	40.22	61.15	72.26
5	59.74	12.08	65.14	49.74	68.87	48.04	62.94	54.62
6	55.83	15.52	65.49	50.00	64.46	33.24	60.79	39.14
7	54.96	15.43	63.83	58.72	59.30	39.56	50.04	40.65
8	59.84	16.04	56.48	64.10	67.80	40.31	63.66	64.30
9	61.82	13.60	60.26	57.18	73.01	46.08	61.08	82.15
10	63.36	12.41	66.57	53.93	77.37	49.19	59.93	75.48
11	61.43	15.45	69.82	50.60	75.21	36.70	62.08	66.45
12	48.52	12.38	54.70	43.93	52.31	29.12	49.17	63.01
13	62.00	10.16	61.98	55.81	68.60	47.58	66.81	75.27
14	54.54	11.61	50.15	49.57	71.13	43.35	52.12	66.88
15	58.25	14.73	59.26	43.25	73.82	37.99	63.23	78.06
16	58.65	15.13	54.56	61.02	76.13	41.47	48.75	79.57
17	60.95	11.97	58.52	56.58	77.69	42.72	63.01	63.87
18	55.15	17.70	51.90	53.50	82.15	28.22	57.78	38.06
19	61.57	15.04	59.17	62.14	71.77	36.05	67.96	70.75
20	50.97	15.94	55.76	52.31	57.15	26.02	47.96	68.17
21	57.55	10.04	55.85	58.12	64.84	42.04	58.50	69.03

Notes:
AVG- Average
STD- Standard Deviation
HOV- Hovering Turn
TO- Take Off
SL- Straight and Level Flight
RDT- Right Descending, Decelerating Turn
LND- Landing
ILS- Instrument Landing System

Table B-4.

Summary of simulator flight maneuver data preoperative day.

Subject	ALL *M*	ALL *SD*	HOV *M*	TO *M*	SL *M*	RDT *M*	LND *M*	ILS *M*
1	62.08	14.42	70.60	66.28	75.70	44.56	43.37	65.65
2	60.15	14.20	63.81	67.05	74.52	40.04	47.01	61.29
3	63.51	11.78	71.75	69.10	70.70	58.44	46.95	51.94
4	56.12	13.84	57.54	58.46	71.08	45.83	37.49	75.00
5	59.76	13.98	58.96	57.95	78.17	57.22	46.81	57.10
6	64.11	16.00	70.31	84.74	64.14	46.98	45.45	67.58
7	59.14	11.97	61.23	72.82	62.74	43.92	46.81	66.29
8	60.40	15.45	69.12	67.18	71.51	31.72	46.95	69.52
9	55.56	12.69	55.54	61.92	72.15	39.47	46.74	45.48
10	62.59	16.22	75.88	70.90	66.18	47.62	38.14	77.10
11	58.23	16.10	65.57	63.20	76.77	48.91	32.90	52.90
12	56.63	12.60	58.95	65.26	67.15	42.18	42.15	62.26
13	59.82	9.75	60.25	61.67	68.60	57.23	55.70	43.71
14	63.16	12.70	70.84	65.38	77.20	48.50	49.25	54.68
15	63.54	13.87	71.81	75.38	70.91	50.86	47.24	47.10
16	63.09	10.65	68.61	69.23	65.65	61.30	46.02	69.68
17	55.40	14.40	59.76	73.08	61.50	30.78	41.29	58.23
18	62.07	15.17	71.33	68.33	72.90	54.83	35.55	67.74
19	62.41	12.32	76.15	69.87	60.91	55.26	46.45	51.77
20	59.75	11.16	72.35	67.05	55.05	50.56	50.90	46.45
21	48.87	14.17	53.03	61.03	55.97	21.87	40.52	53.55

Notes:
AVG- Average
STD- Standard Deviation
HOV- Hovering Turn
TO- Take Off
SL- Straight and Level Flight
RDT- Right Descending, Decelerating Turn
LND- Landing
ILS- Instrument Landing System

Table B-5.
Summary of aircraft flight data preoperative night.

Subject	*M*	*SD*	HOV *M*	TO *M*	SL *M*	RDT *M*	LND *M*	ILS *M*
1	51.81	14.85	52.07	53.76	46.02	45.92	53.12	70.11
2	49.13	15.03	51.80	54.02	55.27	34.87	49.53	32.69
3	55.05	15.25	52.05	46.24	66.61	40.27	61.43	69.25
4	56.38	12.56	57.66	53.16	60.54	45.26	56.06	71.61
5	57.15	17.14	60.63	54.70	66.18	44.10	65.73	23.87
6	56.77	18.14	55.47	63.08	72.04	35.05	59.86	31.40
7	55.26	16.38	58.23	43.50	72.53	38.77	50.54	73.98
8	59.24	15.59	58.75	50.60	65.05	49.05	60.79	85.38
9	59.65	16.37	54.50	60.43	70.00	47.82	53.98	87.53
10	58.40	18.38	60.55	57.27	78.60	37.05	48.96	63.66
11	53.92	19.55	48.70	46.24	69.95	33.94	54.42	88.17
12	51.65	14.83	40.10	45.98	60.00	48.11	58.21	77.20
13	59.43	11.10	64.81	47.86	69.14	45.42	59.38	71.61
14	53.36	13.72	59.87	42.48	58.92	39.87	55.99	62.37
15	59.01	11.91	59.81	58.89	74.36	46.17	52.04	56.77
16	56.26	12.63	55.99	54.44	65.27	53.49	50.54	58.49
17	63.76	13.03	57.30	56.67	80.00	53.13	68.17	70.11
18	52.72	17.45	51.06	45.55	71.40	33.81	50.89	68.17
19	55.56	12.61	57.93	53.50	62.04	47.00	54.70	52.47
20	51.53	13.05	53.09	60.60	57.15	31.80	50.47	43.87
21	55.27	12.09	62.01	51.79	70.06	34.32	49.53	53.55

Notes:
AVG- Average
STD- Standard Deviation
HOV- Hovering Turn
TO- Take Off
SL- Straight and Level Flight
RDT- Right Descending, Decelerating Turn
LND- Landing
ILS- Instrument Landing System

Table B-6.
Summary of simulator data preoperative night.

Subject	ALL *M*	ALL *SD*	HOV *M*	TO *M*	SL *M*	RDT *M*	LND *M*	ILS *M*
1	52.35	11.88	49.96	58.98	64.95	34.14	44.87	63.06
2	51.44	15.71	48.56	64.36	68.71	31.89	38.01	51.77
3	52.47	16.42	49.81	69.10	66.02	42.81	34.05	47.10
4	50.60	11.42	44.81	60.77	63.07	43.34	36.41	62.90
5	57.11	8.62	64.03	55.13	60.92	57.10	47.10	54.03
6	59.01	12.87	60.72	70.64	66.61	52.48	41.43	60.32
7	56.09	16.13	57.41	72.05	67.37	26.69	49.10	48.87
8	54.74	13.67	64.86	61.02	63.22	32.83	43.51	47.42
9	48.97	14.09	38.37	61.15	61.61	45.56	43.23	40.97
10	60.50	16.53	69.32	75.90	70.65	38.27	38.14	60.16
11	50.65	12.64	53.52	55.13	57.53	37.44	41.43	59.19
12	58.88	14.25	61.21	68.84	65.00	49.33	41.00	74.03
13	54.31	15.54	54.19	58.21	69.52	59.49	31.69	55.00
14	59.53	17.81	68.37	68.97	74.68	32.16	43.80	52.42
15	64.07	16.49	74.27	75.26	75.27	48.63	43.22	49.52
16	61.06	12.49	58.29	74.10	68.33	48.80	48.53	73.23
17	53.40	14.75	56.59	68.59	61.61	30.54	41.58	51.61
18	57.29	14.59	65.01	66.66	69.35	47.80	37.63	40.00
19	55.38	13.60	66.05	72.57	45.00	40.38	45.20	52.90
20	55.63	13.46	66.42	69.49	57.15	38.14	39.28	50.32
21	54.14	16.67	56.73	72.56	65.32	28.99	37.64	54.84

Notes:
AVG- Average
STD- Standard Deviation
HOV- Hovering Turn
TO- Take Off
SL- Straight and Level Flight
RDT- Right Descending, Decelerating Turn
LND- Landing
ILS- Instrument Landing System

Table B-7.
Summary of aircraft flight data preoperative NVG.

Subject	ALL *M*	ALL *SD*	HOV *M*	TO *M*	SL *MG*	RDT *M*	LND *M*	ILS *M*
1	51.66	8.92	49.82	48.89	54.89	43.01	57.13	58.46
2	51.30	17.59	56.78	51.28	67.85	35.21	42.87	37.32
3	53.74	18.69	47.20	45.98	72.20	50.96	53.48	54.23
4	53.20	11.83	55.05	51.79	64.52	41.32	53.05	40.36
5	54.00	11.50	59.48	51.11	55.91	39.52	57.85	52.41
6	51.76	18.49	45.97	51.19	73.55	38.79	55.92	24.75
7	53.11	16.14	59.85	43.25	62.74	36.74	56.99	47.86
8	53.26	12.90	48.28	47.01	66.13	49.56	57.78	47.17
9	57.13	13.14	57.44	55.64	62.80	48.58	59.57	53.20
10	59.93	14.71	64.22	54.02	74.19	48.52	54.19	57.80
11	52.20	15.05	52.33	44.45	60.21	39.13	63.73	42.50
12	48.66	10.66	53.13	36.75	55.38	42.28	52.62	47.33
13	61.52	12.16	67.01	52.22	74.68	45.97	62.43	56.40
14	50.42	14.38	58.61	41.80	60.91	32.90	49.75	49.05
15	63.53	12.39	66.67	60.26	76.56	51.14	59.71	57.91
16	61.33	12.06	61.10	62.57	66.18	55.55	61.51	55.00
17	59.58	15.48	52.86	56.41	74.19	48.04	71.69	38.85
18	50.39	13.16	54.84	46.16	62.04	34.50	51.18	39.75
19	53.26	13.60	56.11	61.71	51.29	39.55	54.12	47.22
20	50.09	9.79	50.34	48.20	62.15	36.68	50.32	44.76
21	56.69	13.99	62.41	62.18	68.71	38.23	48.10	49.49

Notes:
AVG- Average
STD- Standard Deviation
HOV- Hovering Turn
TO- Take Off
SL- Straight and Level Flight
RDT- Right Descending, Decelerating Turn
LND- Landing
ILS- Instrument Landing System

Table B-8.
Summary of simulator data preoperative NVG.

Subject	ALL *M*	ALL *SD*	HOV *M*	TO *M*	SL *M*	RDT *M*	LND *M*	ILS *MG*
1	52.98	14.90	49.70	51.41	76.45	37.51	42.37	63.23
2	57.48	14.15	61.89	62.95	60.49	31.73	54.17	75.81
3	55.04	15.80	62.25	60.51	73.06	40.14	32.76	52.42
4	48.96	9.90	46.83	56.67	52.10	45.14	40.57	57.74
5	59.40	11.90	62.68	59.62	74.57	53.91	47.74	46.13
6	55.04	12.74	58.24	68.98	59.41	44.57	44.30	40.48
7	53.64	15.82	55.89	61.41	69.73	25.37	44.44	57.26
8	58.50	15.73	61.55	67.56	77.80	36.54	42.15	54.19
9								
10	62.14	16.26	71.03	74.87	70.81	50.55	36.49	62.58
11	54.24	13.55	57.02	61.67	67.90	40.01	43.37	40.97
12	52.66	14.45	52.18	59.87	70.05	32.49	39.28	61.29
13	56.05	11.59	60.07	51.41	66.45	44.17	52.47	57.10
14	56.29	14.72	59.27	71.16	66.02	31.23	47.67	46.61
15	61.43	12.78	70.75	70.13	64.30	53.01	41.22	66.94
16	56.32	11.31	59.69	57.05	60.54	63.35	37.34	70.81
17	57.57	13.55	59.69	75.39	61.35	48.98	44.37	41.13
18	59.37	17.54	65.90	66.16	78.22	55.01	30.18	52.58
19	57.19	14.10	60.84	55.64	76.35	53.91	40.29	47.10
20	56.62	15.42	61.77	67.44	64.79	38.22	36.56	75.97
21	51.41	16.61	51.59	71.67	62.21	32.20	35.99	42.26

Notes:
AVG- Average
STD- Standard Deviation
HOV- Hovering Turn
TO- Take Off
SL- Straight and Level Flight
RDT- Right Descending, Decelerating Turn
LND- Landing
ILS- Instrument Landing System

Table B-9.
Aircraft IP subjective flight performance scoring for preoperative, day unaided, difficult vs. easy maneuver.

Aircraft By Maneuver							
70' degree OGE Hover Turn (HT)				Straight and Level (SL)			
Subject	2	15	HT *M*	4	8	12	SL *M*
1	3	3	3.0	3	3	3	3.0
2	3	3	3.0	4	3	3	3.3
3	3	4	3.5	4	4	3	3.7
4	3	3	3.0	3	3	3	3.0
5	4	4	4.0	5	5	5	5.0
6	3	3	3.0	5	3	4	4.0
7	3	3	3.0	3	3	3	3.0
8	4	4	4.0	4	4	4	4.0
9	3	2	2.5	4	3	3	3.3
10	4	4	4.0	4	4	4	4.0
11	3	4	3.5	3	4	3	3.3
12	3	2	2.5	3	3	3	3.0
13	4	4	4.0	5	5	5	5.0
14	3	3	3.0	3	4	3	3.3
15	3	3	3.0	5	5	5	5.0
16	3	3	3.0	3	3	4	3.3
17	4	4	4.0	5	5	5	5.0
18	3	4	3.5	4	3	4	3.7
19	3	3	3.0	3	3	4	3.3
20	3	3	3.0	3	4	4	3.7
21	3	3	3.0	3	4	4	3.7
All Subj	3.2	3.3		3.8	3.7	3.8	

Note: Results presented as score on a 1 (worst) to 5 (best) scale

Table B-10.
Simulator IP subjective flight performance scoring for preoperative, day unaided, difficult vs. easy maneuver.

Simulator By Maneuver							
70' degree OGE Hover Turn (HT)				Straight and Level (SL)			
Subject	2	15	HT *M*	4	8	12	SL *M*
1	3	2	2.5	3	3	4	3.3
2	2	1	1.5	3	3	3	3.0
3	3	3	3.0	3	3	2	2.7
4	2	1	1.5	3	3	3	3.0
5	2	2	2.0	3	3	4	3.3
6	3	3	3.0	3	3	3	3.0
7	3	2	2.5	3	3	3	3.0
8	2	2	2.0	3	3	3	3.0
9	2	2	2.0	3	3	3	3.0
10	2	4	3.0	3	3	3	3.0
11	3	4	3.5	3	4	4	3.7
12	3	3	3.0	4	4	4	4.0
13	3	2	2.5	4	4	3	3.7
14	4	3	3.5	4	4	5	4.3
15	2	4	3.0	5	5	5	5.0
16	3	2	2.5	5	5	5	5.0
17	2	2	2.0	3	3	3	3.0
18	1	2	1.5	4	3	4	3.7
19	4	3	3.5	4	4	4	4.0
20	3	2	2.5	4	4	4	4.0
21	1	2	1.5	3	3	3	3.0
All Subj	2.5	2.4		3.5	3.5	3.6	

Note: Results presented as score on a 1 (worst) to 5 (best) scale.

Table B-11.
Aircraft IP subjective flight performance scoring for preoperative, night unaided, difficult vs. easy maneuver.

Aircraft By Maneuver							
70' degree OGE Hover Turn (HT)				Straight and Level (SL)			
Subject	2	15	HT *M*	4	8	12	SL *M*
1	3	2	2.5	3	2	3	2.7
2	2	2	2.0	3	3	3	3.0
3	2	4	3.0	3	3	4	3.3
4	3	2	2.5	3	3	3	3.0
5	4	4	4.0	5	4	4	4.3
6	3	3	3.0	4	4	4	4.0
7	2	3	2.5	3	3	3	3.0
8	2	3	2.5	3	3	3	3.0
9	3	2	2.5	3	3	3	3.0
10	3	4	3.5	4	4	4	4.0
11	2	3	2.5	3	3	3	3.0
12	2	1	1.5	4	3	4	3.7
13	3	3	3.0	5	5	5	5.0
14	3	3	3.0	4	5	4	4.3
15	4	4	4.0	5	5	5	5.0
16	3	2	2.5	3	3	3	3.0
17	4	4	4.0	5	5	5	5.0
18	2	2	2.0	4	5	5	4.7
19	3	1	2.0	4	3	3	3.3
20	4	2	3.0	3	3	3	3.0
21	2	2	2.0	4	4	4	4.0
All Subj	2.8	2.7		3.7	3.6	3.7	

Note: Results presented as score on a 1 (worst) to 5 (best) scale.

Table B-12.
Simulator IP subjective flight performance scoring for preoperative, night unaided, difficult vs. easy maneuver.

70' OGE Hover Turn (HT)				Straight and Level (SL)			
Subject	2	15	HT *M*	4	8	12	SL *M*
1	1	1	1.0	4	3	4	3.7
2	1	2	1.5	2	3	3	2.7
3	2	1	1.5	3	3	3	3.0
4	1	2	1.5	3	3	3	3.0
5	4	4	4.0	4	5	4	4.3
6	2	2	2.0	3	3	3	3.0
7	2	2	2.0	3	3	3	3.0
8	1	2	1.5	3	3	3	3.0
9	1	1	1.0	3	3	3	3.0
10	2	3	2.5	3	3	3	3.0
11	1	1	1.0	3	4	4	3.7
12	3	2	2.5	4	2	3	3.0
13	2	2	2.0	3	4	4	3.7
14	2	3	2.5	4	4	4	4.0
15	2	1	1.5	5	5	4	4.7
16	2	2	2.0	5	5	5	5.0
17	2	2	2.0	3	3	3	3.0
18	3	2	2.5	4	4	4	4.0
19	3	3	3.0	4	3	4	3.7
20	2	3	2.5	3	3	4	3.3
21	1	2	1.5	3	3	4	3.3
All Subj	1.9	2.0		3.4	3.4	3.6	

Note: Results presented as score on a 1 (worst) to 5 (best) scale.

Table B-13.
Aircraft IP subjective flight performance scoring for preoperative, NVG, difficult vs. easy maneuver.

Aircraft By Maneuver							
70' OGE Hover Turn (HT)				Straight and Level (SL)			
Subject	2	15	HT *M*	4	8	12	SL *M*
1	2	2	2	3	3	3	3.0
2	2	2	2	3	3	3	3.0
3	3	2	2.5	3	3	3	3.0
4	3	3	3	3	3	3	3.0
5	3	3	3	5	5	5	5.0
6	4	3	3.5	4	4	4	4.0
7	1	2	1.5	3	2	3	2.7
8	2	2	2	3	3	3	3.0
9	3	3	3	4	4	4	4.0
10	3	3	3	4	4	4	4.0
11	2	2	2	3	3	3	3.0
12	3	3	3	4	3	3	3.3
13	3	3	3	5	5	5	5.0
14	2	2	2	4	4	4	4.0
15	4	4	4	5	5	5	5.0
16	2	2	2	3	3	3	3.0
17	4	2	3	5	5	5	5.0
18	3	3	3	5	5	5	5.0
19	2	3	2.5	3	4	4	3.7
20	3	3	3	3	3	3	3.0
21	2	2	2	4	4	4	4.0
All Subj	2.6	3.1		3.8	3.7	3.8	

Note: Results presented as score on a 1 (worst) to 5 (best) scale.

Table B-14.
Simulator IP subjective flight performance scoring for preoperative, NVG, difficult vs. easy maneuver.

Simulator By Maneuver							
70' OGE Hover Turn (HT)				Straight and Level (SL)			
Subject	2	15	HT *M*	4	8	12	SL *M*
1	1	2	2.5	3	4	3	3.3
2	3	1	1.5	2	2	3	3.0
3	3	2	3	3	3	3	2.7
4	2	2	1.5	2	3	3	3.0
5	4	4	2	4	4	4	3.3
6	3	2	3	3	3	3	3.0
7	3	1	2.5	3	3	3	3.0
8	2	1	2	3	3	3	3.0
9	1	1	2	3	2	3	3.0
10	2	3	3	3	3	3	3.0
11	3	2	3.5	3	3	4	3.7
12	2	1	3	3	3	3	4.0
13	3	4	2.5	3	3	3	3.7
14	2	2	3.5	4	4	3	4.3
15	1	2	3	3	5	5	5.0
16	3	2	2.5	5	5	5	5.0
17	2	2	2	3	3	3	3.0
18	1	2	1.5	4	5	5	3.7
19	2	2	3.5	4	4	4	4.0
20	2	2	2.5	4	4	4	4.0
21	2	1	1.5	3	3	3	3.0
All Subj	2.5	2.4		3.5	3.5	3.6	

Note: Results presented as score on a 1 (worst) to 5 (best) scale.

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